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Characterization and Modeling of Plumes and Animal Plume-Tracing in Wave-influenced Coastal Environments

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13. ABSTRACT *(Maximum 200 words)*

This study focused on understanding how peripheral and central encoding of chemical detection signals are accomplished, and determining which spatial and temporal properties of chemical plumes are of most importance to plume-tracing animals. We performed laboratory experiments to examine the odor-tracing behavior of the stomatopod *H. ensigera* in unidirectional and wave-influenced flow environments, and correlated tracing maneuvers with the simultaneously-recorded characteristics of the odor plume at the position of the animals' olfactory antennules. We also performed a combination field data collection/modeling research program to characterize the dynamics of a plume from a near-bed source in near-coastal waters. We found that odor plumes in both unidirectional and wave-affected flow consist of very thin filaments of high concentration interspersed with clean water, but odor filaments encountered by the antennules have both a higher maximum odor concentration and a higher mean odor concentration in wave-affected flows. This is the first recording of the exact chemical information an animal is getting as it navigates to a source in a realistic flow environment. The field experiments revealed that the plume's vertical extent is entirely determined by the source height and the thickness of the near bottom mixed layer, which is set by the local stratification.

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FINAL REPORT

GRANT #: N00014-98-1-0785-P00001

PRINCIPAL INVESTIGATORS: Jeffrey R. Koseff and Stephen G. Monismith

INSTITUTION: Stanford University

GRANT TITLE: Characterization and Modeling of Plumes and Animal Plume-Tracing in Wave Influenced Coastal Environments

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OBJECTIVE: Our long-term objectives were (1) to understand how peripheral and central encoding of chemical detection signals are accomplished; (2) to determine which spatial and temporal properties of chemical plumes are of most importance to plume-tracing animals, and (3) to provide data for the testing and implementation of a real-time search strategies developed by other researchers in the ONR/DARPA Plume Tracing Program.

APPROACH: In collaboration with Mimi Koehl at UC Berkeley we performed laboratory experiments to: (i) examine the odor-tracing behavior of the stomatopod *H. ensigera* in wave-influenced flow environments; (ii) to compare that with their plume-tracing behavior in unidirectional flow; and (iii) to correlate tracing maneuvers with the simultaneously-recorded characteristics of the odor plume at the position of the animals' olfactory antennules. In addition, in collaboration with Tom Powell at UC Berkeley, we performed a combination field data collection/modeling research program to characterize the dynamics of a plume from a near-bed source in near-coastal waters.

ACCOMPLISHMENTS: We have completed the following tasks in the laboratory. First, we acquired plume image datasets (see Table 1 for summary) for different flowspeeds and different flow conditions (unidirectional and wave-influenced). The task involved taking long time histories of the plume in various locations in order to calculate plume properties such as mean concentration, standard deviation, and intermittency. Second, we coordinated with Mimi Koehl at UC Berkeley to introduce live animals into our laboratory plumes. We simultaneously acquired datasets of odor plume structure (in both the unidirectional and wave-affected flows) and live animal-tracking behavior to investigate the real-time search strategies of the animals. An example of an image, which was acquired in this dataset, is shown as Figure 1. This image shows a stomatopod encountering an odor filament (see paper by Mead et al, 2002) while moving through an odor plume in a wave-influenced flow.

In the field, a series of four experiments were conducted (Hydro 1.5, 2, 2.5, and 3) from November 1998-June 2000 at San Clemente Island, CA. These tests resulted in both detailed hydrodynamic information relevant to plume dispersal in the bottom mixed layer, as well as a progressive and rapid advancement in plume measurement techniques. The Hydro experiments documented many of the hydrodynamic variables important to characterizing plume dispersal in the benthic coastal zone. A suite of data were

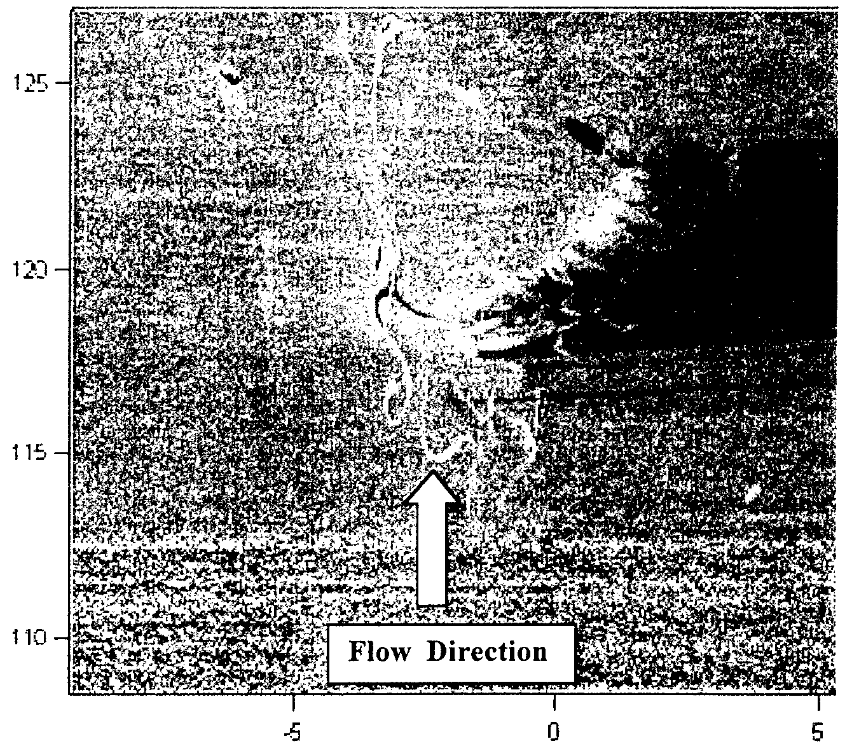

Figure 1: A plan view of a stomatopod encountering an odor filament in a wave-influenced flow. The stomatopod is at a distance of 120 source diameters from the source of the odor.

collected including fixed measurements of temperature, wave amplitude, and Reynolds stresses, and velocity profiles. The latter included detailed measurements of the near-bottom flow structure, which was approximated well by a log-layer, fit. The Reynolds stress measurements revealed that the bottom boundary layer the measured fluctuations were due in part to both turbulent momentum fluxes and wave activity. The mean flow velocimetry was invaluable to predicting the mean plume evolution tendencies. In addition to the fixed location measurements, larger survey data sets of velocity, density, and dye concentration were collected using shipboard mounted instruments. The first experiments (1.5 and 2) involved the building of an inexpensive tow body constructed of PVC. This platform provided the first ever regularly-gridded measurements of a dye plume at a fixed depth.

<u>CONCLUSIONS</u>: From the laboratory experiments we can conclude the following. First, odor plumes in both unidirectional and wave-affected flow consist of very thin filaments of high concentration interspersed with clean water. As a result there is extreme variability in both space and time in the arrival of signal at the sensors. Second, in general, odor filaments in wave-affected flows are wider on average than filaments in unidirectional flows.

Table 1: Record of Plume Experiments

Ave Velocity (cm/s)	Depth (cm)	Width (cm)	Waves	Animals	Sheet	X (cm)	Y (cm)	Z (cm)	Long	Movie	LDA
5	41	122	uni	Y	Horiz	57.5	0	2	N	Y	Y
2	38.3+-1.2	122	waves	Y	Horiz	30.5	5.1	2	N	Y	Y
5	38.3+-1.2	122	both	N	Horiz	30.5	0	2	Y	Y	Y
5	38.3+-1.2	122	both	N	Horiz	30.5	0	1.3	Y	Y	Y
5	38.3+-1.2	122	both	N	Horiz	59.5	-0.5	2	Y	Y	Y
5	38.3+-1.2	122	both	N	Horiz	160.5	0.5	2	Y	Y	Y
5	38.3+-1.2	122	both	N	Horiz	160.5	-17.0	2	Y	Y	Y
5	38.3+-1.2	122	both	N	Vert	66.6	0	8.7	Y	Y	Y
2	41.2+-0.8	122	waves	N	Horiz	30.5	0	2	Y	Y	Y
2	41.2+-0.8	122	waves	N	Horiz	30.5	0	1.3	Y	Y	Y
2	41.2+-0.8	122	waves	N	Horiz	59.5	-0.5	2	Y	Y	Y
2	41.2+-0.8	122	waves	N	Horiz	160.5	0.5	2	Y	Y	Y
2	41.2+-0.8	122	waves	N	Horiz	160.5	-17.0	2	Y	Y	Y
2	41.2+-0.8	122	waves	N	Vert	66.6	0	8.7	Y	Y	Y

Notes:

- x: streamwise distance from source to plane or center of image (cm)
- y: spanwise distance from source to plane or center of image (cm)
- z: vertical distance from source to plane or center of image (cm)

1. "Long" means we took 4000 to 8000 images at 0.44 Hz (roughly 2.5 to 5 hours of data).
2. "Movie" means we took 100-150 images at 15 Hz.
3. "LDA" means we have a velocity profile of LDA data for the flow condition

Note: For both "Long" and "Movie", each image frame covers approximately 18cm x 18cm of the flow, with spatial resolution of 180 microns. The images are 12-bit (4096 gray levels).

Third, the maximum available (to the stomatopod in any region of the flow) concentrations are similar in both flow conditions, but the mean available concentration is greater in wave-affected flows. Finally, odor filaments encountered by the antennules have both a higher maximum odor concentration and a higher mean odor concentration in wave-affected flow than in unidirectional flow. The field experiments revealed a simple, succinct description of plume dispersal in the nearshore environment. The basic results of the tests were: (1) The plume's vertical extent is entirely determined by the source height and the thickness of the near bottom mixed layer, which is set by the local stratification.(2) The downstream plume concentration and meandering are captured well by relatively simple and easy to implement modified advection-diffusion models. (3) The macroscopic plume characteristics are, in theory, capable of being captured by a single measurement platform.

SIGNIFICANCE: Our laboratory experiments have provided us with the instantaneous, fine-scale chemical signal encountered by mantis shrimp as they track odor plumes in wave-affected and unidirectional flow. This is the first time that it has been possible to know exactly what chemical information an animal is getting as it navigates to a plume source in a realistic flow environment. We can use information from these experiments to generate a list of behaviors used by the animals that correlate with particular aspects of concentration or concentration change at their antennules. This list should be helpful in comparing the search "rules" used in waves versus in unidirectional flow, and should provide insights for the generation of search algorithms for man-made plume-tracing devices for use in coastal habitats. The field component has been directed at developing and determining the efficacy of candidate plume-dispersal models, search strategies, and target-localization inverse algorithms through a series of experiments where plumes of dye were created to represent surrogates for plumes containing explosives in the natural ocean environment. The measurements from a tow body showed a plume trapped to the confines of the bottom mixed layer and also suggested the importance of measurements at a fixed altitude. The Hydro 2.5 and 3 experiments saw the successful implementation of a Guildline Minibat tow body that captured detailed measurements of a dye plume from a fixed altitude above the bottom.

AWARD INFORMATION: Koseff was appointed the Senior Associate Dean of Engineering as of September 1999. Monismith received the Eugene L. Grant Award for Teaching…

PUBLICATIONS AND ABSTRACTS:

Journal Articles:

Stacey, M.T., Cowen, E.A., Powell, T.M., Monismith, S.G., Koseff, J.R., and Dobbins, E., "Plume Dispersion in a Stratified, Near Coastal Flow: Measurements and Modeling", *Continental Shelf Research*, 20(6), 2000, pp. 637-663.

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Cowen, E.A., Stacey, M.T., Dobbins, L., Monismith, S.G., Powell, T.M., and Koseff, J.R., "Plume Measurements in Shallow Coastal Waters at Scales of Several Hundred Meters", 1998 Ocean Sciences Meeting, Paper OS22N-05, Feb 8-12, 1998.

Crimaldi, J.P., Wiley, M.B., and Koseff, J.R., " Design and Quantification of a Laboratory Odor Plume for use in Biological Studies of Chemical Sensing and Tracking Algorithms", Limnology and Oceanography: Navigating into the Next Century, ASLO Meeting, Santa Fe, New Mexico, February 1-5, 1999, pp. 51.

Stacey, M.T., Musiak, J.D., Sereno, D., Powell, T.M. and Monismith, S.G., "Dye dispersion in a stratified near-coastal flow over a sloping bottom", presented at AGU/ASLO Ocean Sciences Meeting, San Antonio, Tx, Jan 24-28, 2000.

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Crimaldi, J.P., Koseff, J.R., and Koehl, M.A.R., "Size does matter: The effect of sensor morphology and kinematics on perception," Making Connections in the 21st Century, 2001 ASLO Aquatic Sciences Meeting, Albuquerque, New Mexico, February 12-16, 2001, p. 40.

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